【 Article 】

A Study of Disassembly Estimation and Improvement of Home Appliances

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Abstract

To increase the recyclability of home appliances, it is important to disassemble the parts that can be recycled and those that consist of hazardous materials at the early stage of disassembly. It is therefore important to design a product that can be disassembled easily. This study shows the possibility of the development of environmental or "green" products through the analysis of the assembly and the disassembly of an automatic washing machine. This analysis can reduce a complicated structure to a simple one and also leads to simpler manufacturing processes. The analysis and improvement of the financial consequences of disassembly can maximize profit at the end of a product's life, and allows a determination of when to stop disassembly.

Key words : recycling, disassembly time, financial line, waste product

Introduction

With recent economic growth, the improvement in consumer living standards, and consequently the production of more sophisticated products by manufacturers, the number of home appliances reaching the end of their life cycles is increasing every year and their disposal has become a severe social problem. Reduction and waste recycling are therefore a matter of urgent consideration.

The U.S., E.U., Japan and many other countries are going to great pains to create waste reduction and recycling regulations to cope with this situation. In Korea, businesses are trying to

develop environmentally conscious products, or ECP, and are performing product assessment at the development stage. This is based on the government's announced "Recycling Guide for Firstly Appointed Companies", which obliges them to perform preassessments of home appliance recycling (product assessment) from 1994.

Improvements in design and production processes for more efficient manufacturing has been a major competitive issue for decades and will continue to be an essential factor in the future. Growing interest in the global environment requires that we should design products and choose materials for easy disassembly and effective product life. Methods to assess mechanical durability and electrical performance in designing home appliances are well established, but objective and reasonable ways for their assessments are still being studied¹⁾.

This research is aimed at the simplification of product structures, thus making disassembly and recycling easy and shortening disassembly time.

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We have tried to solve these problems by analyzing the assembly and disassembly of an automatic washing machine for easier disassembly, which is the basis of recyclability. With analysis and improvement of the financial consequences of disassembly in terms of minimization of disposal cost and economical recycling, we suggest criteria to determine the point at which disassembly should stop.

Subject

Analysis and Improvement Procedures.

We analyzed the assembly and disassembly of an existing automatic washing machine through the procedures in Fig. 1 to change the structure for easy disassembly, and to make shorter disassembly time with maximum profits. DFA (Design for Assembly) and DFS (Design for Service) software developed by Boothroyd Dewhurst, Inc. in the U.S. were used to simplify the product structure and estimate disassembly time. This research conducted by DFD worksheet and financial line was the result of co-operative studies done with University of Rhode Island in USA.

Assessment of Disassembly & Determination of the Financial Line^{2, 3)}

We analyzed the assembly of an automatic

Fig 1 Flow chart of analysis and improvement

washer on the market for the first time by DFA software, the result of which is shown in Table 1. Total assembly time is automatically estimated based on time data base of software provided that characteristics such as shape, class, size, symmetry, handling difficulties, insertion difficulties, etc. are input onto the questions screen of DFA software for each part making up the automatic washing machine. The No. of operations means the number of activities requiring assembly time, but where no parts are added. Examples of this are greasing and taping operations. The theoretical minimum No. of parts is the ideal minimum number of parts to build the product.

The results of the DFA analysis were transferred to a DFS software program, which generated a DFD (Design for Disassembly) worksheet giving estimates of the disassembly time for each part and operation. This was carried out using Microsoft Excel software and included, for each item, the life-end destination, the disassembly cost related to disassembly time, the cost for disposing of the remaining parts of the product when there is no further disassembly, profit or loss and the net value. The worksheet was utilized to draw a financial line where the profit or loss at any stage in disassembly is plotted against the disassembly time.

In Table 2, a DFD worksheet for the automatic washing machine is presented. The meaning of each items is as follows :

1. Step i
Number given to part, subassembly or operation.
2. Name
Name of part, subassembly or operation.
3. Repeat count
Number of identical parts or operation at Step

Table 1 Results of DFA analysis of an automatic washing machine

Item	Automatic Washing Machine	Remarks
Total assembly time (sec)	2,143.1	Packing was excluded
Total no. of parts (each)	284	
Total no. of operations (each)	74	
Theoretical minimum no. of parts (each)	76	
Weight of product (kg)	55	

Table 2 DFD worksheet for Automatic washing machine

Step	Name	RP	End of Life Destination	Material	Weight (g)	Disassembly Time (sec)		Disassembly Cost (₹)		Remainder Weight (g)		Disposal Cost (₹)	Profit (₹)	Profit Cum (₹)	Total Profit (₹)	Total Effect (₹)
						Tdi	Tcum	Cdi	Ct	Wr (i)	Cdisp					
i		EA			Wi	Tdi	Tcum	Cdi	Ct	Wr (i)	Cdisp	Pi	Pt	Ctot		
1	SEW-1096 W	1	DUMP	MIX	55,000	0	0	0	0	0	0	-880	-879.6	-879.6	-879.6	
2	CLIP-RING S	1	DUMP	Fe	1	5	5	-6.12	-6.12	54,999	-879.98	0.1	0.1	-886	-886	-6.4
3	DRAIN-HOSE	1	DUMP	MIX	271	5	10	-6.12	-12.24	54,728	-875.65	-4.336	-4.236	-892.13	-892.13	-6.13
4	SHUTTER	1	RECYCLE	PP	518	3.8	13.8	-4.65	-16.89	54,210	-867.36	113.96	109.72	-774.53	-774.53	117.6
5	SCREW-EARTH WIRE	1	RECYCLE	Cu	1.5	9.9	23.7	-12.12	-29.01	54,208.5	-867.34	1.77	111.49	-784.86	-784.86	-10.33
6	ASSY-EARTH WIRE	1	DUMP	MIX	52.7	3.8	27.5	-4.65	-33.66	54,155.8	-866.49	-0.8432	110.65	-789.5	-789.5	-4.64
7	SCREW-COVER BACK	2	RECYCLE	Fe	2.5	15.6	43.1	-19.11	-52.77	54,153.3	-866.45	0.25	110.9	-808.32	-808.32	-18.82
8	COVER-BACK	1	RECYCLE	PP	447	18.4	61.5	-22.53	-75.3	53,706.3	-859.3	98.34	209.24	-725.36	-725.36	82.96
9	CUFF-D	1	RECYCLE	ABS	10	13.5	75	-16.53	-91.83	53,696.3	-859.14	5.5	214.74	-736.23	-736.23	-10.87
10	Push fit unfasten	1	-	O	0	3.6	78.6	-4.41	-96.24	53,696.3	-859.14	0	214.74	-740.64	-740.64	-4.41
11	CLIP-RING S	1	RECYCLE	Fe	1	5	83.6	-6.12	-102.36	53,695.3	-859.12	0.1	214.84	-746.64	-746.64	-6
12	Snap fit unfasten	1	-	O	0	1.8	85.4	-2.2	-104.56	53,695.3	-859.12	0	214.84	-748.84	-748.84	-2.2
13	SCREW-COVER TC	2	RECYCLE	Fe	6.1	15.6	101	-19.11	-123.67	53,689.2	-859.03	0.61	215.45	-767.25	-767.25	-18.41
166	LEG-GOLD	2	RECYCLE	ABS	76	7.6	1,695.3	-9.31	-2,076.16	14,702	-235.23	41.8	11,226	8,914.72	8,914.72	33.71
167	HOLDER-LEG	2	DUMP	FRPP	24	15.6	1,710.9	-19.11	-2,095.27	1,4678	-234.85	-0.384	11,226	8,895.61	8,895.61	-19.11
168	BASE	1	RECYCLE	PP	1,680	4.8	1,715.7	-5.88	-2,101.15	1,2998	-207.97	369.6	11,595	9,286.21	9,286.21	390.6
169	FLAME	1	RECYCLE	FE	12,998	4.8	1,720.5	-5.88	-2,107.03	0	0	1,299.8	12,895	10,788.1	10,788.1	1,501.9

i.

R1 : ₹ 4,409/hr (wage per hour)

4. Life-end Destination

Final disposal destination after disassembly (separation, recycling, reuse, landfill disposal and incineration with regular or special treatment)

5. Material

Material contained in parts or subassembly. '—' stands for operation.

6. Weight of Part (g), W_i

Weight of part or subassembly at Step i.

For a subassembly that is not disassembled and analyzed, the weight of each part is excluded as it must be recorded only once. The weight of an operation is given as "0".

7. Disassembly Time (sec), T_d

These times are based on DFS disassembly times and include times for operations such as special dismantling, wire cutting and snap-fit breakage.

8. Cumulative Disassembly Time (sec), T_{cum}

$$T_{cum} = \sum_{i=1}^n T_{di} \quad (1)$$

This is the disassembly time until part n is removed.

9. Disassembly Cost (₹), C_{di}

$$C_{di} = T_{di} \times R1 \times (1\text{hour} / 3,600\text{sec}) \quad (2)$$

This is the cost of disposal at each step of the disassembly sequence.

10. Cumulative Disassembly Cost (₹), C_t

$$C_t = \sum_{i=1}^n C_{di} \quad (3)$$

The total cost of disassembly until step n.

11. Weight of the Remainder (g), $W_r(i)$

$$W_r(i) = W_r(i-1) - W(i) \quad (4)$$

The weight of the remaining parts after each step, which will be used to compute disposal cost in case disassembly is stopped at step i.

12. Cost for Disposal of the Remainder (₹)

$$C_{disp} = W_r(i) \times ₹/g \text{ (landfill cost)} \quad (5)$$

The total cost for the disposal of the remainder of the product in case disassembly is stopped at step i.

13. Profit (₹), P_i

According to the life-end destination, one of the following expressions is used to calculate profits obtained at the final destination.

1) If item i is landfilled,

$$P_i = W_i \times ₹/g \text{ (not related to weight of the remainder)} \quad (6-1)$$

2) If item i is reused,

$$P_i = 1/3 \times (\text{the value of the original part}) \quad (6-2)$$

3) If item i is recycled,

$$P_i = W_i \times (\text{Sales, ₩/g}) \quad (6-3)$$

The sales price for each kind of recyclable material in Korea is as follows :

Fe-about ₩ 100/kg, SUS-₩ 350/kg, ABS-₩ 550/kg, PP-₩ 220/kg, etc.

14. Cumulative profit

$$Pt = \sum_{i=1}^n P_i \quad (7)$$

The total profit arising from disassembly until step n .

15. Total profit(₩), C_{tot}

$$C_{tot} = Pt - Ct - C_{disp} \quad (8)$$

This shows the financial consequence and cumulative profit and loss after each step of disassembly. It is not the same as the profit for each part, the cumulative cost of disassembly or the disposal cost of the remainder.

16. Total Effect

$$EFFECT_i = C_{tot}(i) - C_{tot}(i-1) \quad (9)$$

The result of step i , total profit and loss. If '−', it is a loss and the slope is negative. If '+', it is a gain and the slope is positive.

Finally on the basis of Table 2, the financial line for the disassembly of a washing machine

using a reverse of the assembly sequence (before redesign) is shown in Fig.2. The abscissa is disassembly time and the ordinate is total profit. Any point on the financial line depicts the cumulative cost of disassembly, the cumulative profit or loss resulting from parts that are to be recycled and the disposal cost of the remainder.

The line shown in Fig.2 begins at a negative value representing the disposal cost of the entire product (landfilled without dismantling); a cost of about ₩880 would have been incurred (landfill cost of general waste in Korea; about ₩16/kg).

Expenses such as labor cost and disposal fees at each step of disassembly increase in proportion to disassembly time. Accordingly disassembled parts are disposed of by landfill or incineration without recycling, the graph shows losses and the slope is negative. When profits are gained from sales of parts made of recyclable plastic or metals, the slope is positive. For example, disassembly time up until the top-cover was removed is 583 seconds and sales of the materials, recyclable plastic (ABS), yield a profit of ₩ 1,263 (sale cost at ₩550/kg), and so it shows a positive value and creates a positive slope. Shown as Table 2, about ₩ 12,895 worth's profit made and it takes 1,720.5 seconds, so about ₩ 2,107 of disassembling cost is generated in the case where all parts of the automatic washing machine are disassembled completely and parts available for recycling, such as steel, PP, ABS, etc., are sold.

Accordingly, we can see that it is possible to

Fig. 2 Financial line for the original design of the washing machine

obtain about ₩10,788 worth's of total profit when all parts of the automatic washing machine are disassembled completely.

“Optimizing” the Disassembly Sequence and Effect Analysis

A CE (Concurrent Engineering) team composed of staff in charge of design, production, quality, manufacturing skills, service, and purchase, was organized to improve existing products. The assembly and disassembly of an automatic washing machine were analyzed first. To increase the recyclability, overall improvement of not only disassembly, but also assembly and service of key parts, was carried out.

The CE team proposed many design improvements including reduction of parts, changes in assembly procedures, changes in product structure, and changes in materials, stressing that toxic parts and recyclable or reusable parts should be removed at the early stage of disassembly.

Table 3 shows the DFA analysis of a redesign-

Table 3 DFA Analysis of an improved washing machine

Item	Washing Machine	Improvement Ratio
Total assembly time (Sec)	1,639.7	23.5
Total no. of parts (each)	209	26.4
Total no. of operation (each)	63	14.9
Minimum no. of parts theoretically required (each)	72	—
Weight of Product (kg)	48.5	11.8

ed washing machine. Its financial line for disassembly is shown in Fig. 3 where weight-reduction of products yielded a landfill cost of ₩767 without disassembly. Rearrangement of the disassembly sequence and betterment of structure continued so that ASS'Y PCB containing toxic material, lead and valuable parts like plastic and metals are removed at the early stage of disassembly.

Table 4 presents a comparison of the DFD analysis for the completely disassembled washing machine both before and after redesign. The cost of disassembly decreased due to reduction of the disassembly time after improvement, and profit and total profit were also reduced by reduction of the number of recyclable parts, weight-reduction of parts, etc. Though the total profit was reduced by 7.4%, the disassembly time to remove all the parts was reduced by 23.5% and the average rate of total profit per hour was raised by 21%. Fig. 4 shows the results of the analysis in bar chart form.

For comparison purposes, the financial lines before and after optimization are shown in Fig. 5 and present the effects of optimizing the disas-

Table 4 DFD analysis of the washing machine Before and After Redesign

Item	Washing Machine		Difference
	Before redesign	After redesign	
Landfill cost (₩)	— 880	— 767.2	112.8
(Weight of the Product : kg)	(55)	(48.5)	(6.5)
After the last Part was disassembled			
Disassembly time (sec)	1,720.5	1,316.1	404.4
Cost of disassembly (₩)	— 2,107	— 1,611.8	495.2
Profit (₩)	12,895	11,602.8	1,292.2
Total profit (₩)	10,788	9,991	797

Fig. 3 Financial line for the redesign of the washing machine

Fig. 4 Disassembly data comparing the original design and redesign of the washing machine

Fig. 5 Financial lines for the original design and redesign of the washing machine

sembly sequence. The cost of initial disposal is negative because a toxic item, ASS'Y PCB, was incinerated or landfilled without disposing of the lead, which is a harmful material. It is important to disassemble such items containing hazardous materials first and dispose of them safely so as not to pollute the environment.

When a product is disassembled, the financial line begins at a negative value representing the disposal cost of the entire product and will rise whenever significant profits are gained from reusing or recycling components. The line will fall when labor cost and disposal fees exceed any profits. In order to increase profits or decrease loss due to partial disassembly, the most valuable parts should be removed at the earliest possible stage of disassembly.

Deciding when to Stop Disassembling

There are many criteria that might be used in deciding when to stop disassembling. For example, the point of maximum profit or minimum loss in disassembly might be selected. Looking at financial lines from this point of view makes it clear which point is the best to stop disassembling.

In Fig. 5, the time when the highest rate of profit is achieved can be calculated by dividing the profit at any point on the financial line by the disassembly time. Thus, if a line is drawn from the origin to that point on the financial line, the slope gives the rate of profit. Therefore, the point on the financial line that creates the highest slope would also be the point at which disassembly could be stopped for the highest rate of profit. The fortieth

disassembled part is Motor-Assay in case parts of the automatic mashing machine are disassembled one by one. Fig. 5 shows that the highest rate of profit obtainable for the washing machine is after the removal of 40 critical parts. In the present design, this takes 1,124 sec and the redesign takes 371 sec.

Accordingly, to minimize disassembly cost and to obtain the highest rate of profit, it is most desirable that the rest of the parts are not disassembled but put out as waste after removal of Motor-Assay that was disassembled forty times.

However, it is unlikely that the removal of 40 parts from the product and disposal of its remainder would be satisfactory from an environmental point of view. If most parts are recyclable in a washing machine, it is desirable that all of them are disassembled and then recycled or reused. We must think comprehensively, of the government's environmental policies, disposal and recycling techniques, economic aspects, impact on the environment, etc. to determine the point where disassembly should stop.

Conclusions

Assessment of disassembly in terms of time and cost have been suggested, and ways to solve various problems using DFA and DFD worksheets

and financial lines were proposed. Analysis and improvement of disassembly help maximize profit and illustrate criteria to determine the point at which disassembly should be stopped.

During profit design, manufacturers have tried to reduce assembly time by reducing the number of parts, standardization of parts and design of parts for efficient manufacture. However, environmental problems are becoming more serious and products must be designed to improve recyclability by consideration of their influence on the environment from the early stages of design to their disposal. New designs should make after-service easy in order to lengthen the life expectancy, and designers need to develop techniques to simplify disassembly and recycling. Assessment of disassembly should include disassembly time, the cost of disposal, and conformability of materials of parts to environmental aspects in the future.

References

- 1) 大西 宏, 寺田貴彦, 清水時彦: 家庭電化製品に対する分解性評価方法の検討, 廃棄物学会論文誌, Vol. 6, No. 1, pp. 1-6 (1995)
- 2) "Disassembly Spreadsheet", University of Rhode Island, Report to Samsung dated April 7 (1995)
- 3) "Generation of Disassembly Sequence", University of Rhode Island, Report to Samsung dated April 7 (1995)

家電製品の分解性評価と改善に関する研究

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【要 旨】 家電製品のリサイクルを向上させるために、廃棄時にリサイクルまたは再利用が可能な部品および有害物質が含まれた部品を、製品分解の初期段階で分解が可能なようにし、全ての部品が容易く分解されるようにすることが重要だ。

このために、本論文では全自動洗濯機の組立性と分解性の分析を通じて、作業の沮害要因と各種の問題点を改善することにより、環境にやさしい製品の開発が可能であるということを提示する。また財政ラインの分析と改善により、製品の廃棄時に財政利潤の最大化を持たらすことができるようにし、最適な分解終了時点を決する基準を提示できるようにする。

キーワード： 再利用，分解時間，財政ライン，廃家電